18-Specialty Transformers

ECEGR 450
Electromechanical Energy Conversion

Overview

- Autotransformers
- Center-tapped Transformers
- Current Transformers
- Potential Transformers
- Regulating Transformers

Autotransformers

- Transformers discussed so far have electrical isolation from primary to secondary
- Possible to connect primary and secondary electrically
  - Series mutual inductive circuits
- Power is transferred to load via conduction and induction
- Autotransformers are particularly useful when voltage transformation is between 1:3 and 3:1
- Often grounded Y-connected if three phase

Autotransformer Benefits

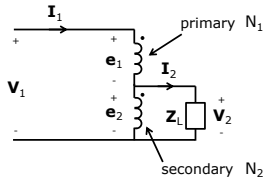
- When compared to conventional two-winding transformers, autotransformers offer:
  - More inexpensive construction
  - Greater power density
  - Higher efficiency
  - Lower excitation current to establish the same flux

Autotransformer Drawbacks

- When compared to conventional two-winding transformers, autotransformers offer:
  - No electrical isolation between primary and secondary
  - Higher short-circuit current

Ideal Autotransformer Model

Primary and secondary windings connected ("common winding")



Ideal Autotransformer Model

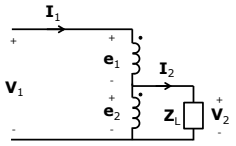
Transformer ratio:

$\mathbf{V}_1 = \mathbf{e}_1 + \mathbf{e}_2$

$\mathbf{V}_2 = \mathbf{e}_2$

$\frac{\mathbf{V}_1}{\mathbf{V}_2} = \frac{\mathbf{e}_1 + \mathbf{e}_2}{\mathbf{e}_2} = \frac{N_1 + N_2}{N_2} = 1 + a = a_T$

Recall: $a = \frac{N_1}{N_2}$



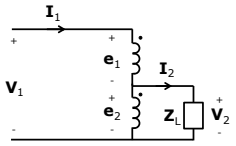
since $a_T > 1$, this configuration is a step-down autotransformer

Ideal Autotransformer Model

By Ampere's Law (sum of mmf = 0 due to ideal assumption)

$(N_1 + N_2)\mathbf{I}_1 = N_2\mathbf{I}_2$

$\frac{\mathbf{I}_2}{\mathbf{I}_1} = \frac{N_1 + N_2}{N_2} = 1 + a = a_T$

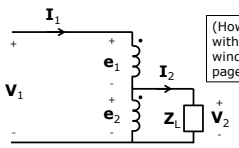


Ideal Autotransformer Model

Apparent power of ideal autotransformer:

$\mathbf{S} = \mathbf{V}_2\mathbf{I}_2 = \frac{\mathbf{V}_2}{a_T}a_T\mathbf{I}_2 = \mathbf{V}_1\mathbf{I}_1$

Real, imaginary and complex power is conserved



(How does this compare with power from a two-winding xfmr? See text page 247)

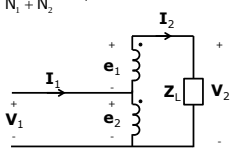
Ideal Autotransformer Model

- Other autotransformer configurations are possible
- Example: step-down autotransformer

$\mathbf{V}_1 = \mathbf{e}_2$

$\mathbf{V}_2 = \mathbf{e}_1 + \mathbf{e}_2$

$\frac{\mathbf{V}_1}{\mathbf{V}_2} = \frac{\mathbf{e}_2}{\mathbf{e}_1 + \mathbf{e}_2} = \frac{N_2}{N_1 + N_2} = a_T < 1$



a_T depends on connection

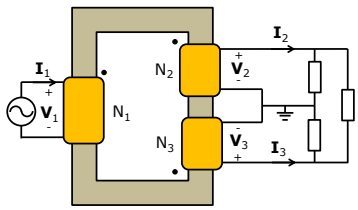
Non-Ideal Autotransformer Model

- Non-ideal autotransformer model has similar elements as non-ideal two winding transformer
  - See ages 250-251 of text
  - See Example 4.10 and 4.11 of text
- Impedances can be transformed from secondary to primary by: $\mathbf{Z}_2 a_T^2$

Center-Tapped Transformers

Consider the shown winding arrangement:

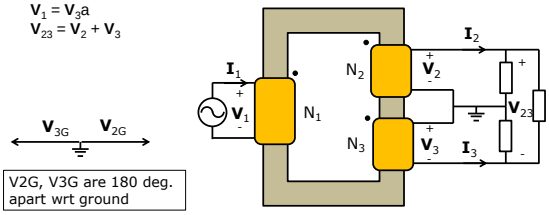
Let $N_2 = N_3$



Center-Tapped Transformers

Let $N_2 = N_3$

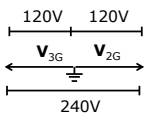
$V_1 = \mathbf{V}_2 a$
$V_1 = \mathbf{V}_3 a$
$V_{23} = \mathbf{V}_2 + \mathbf{V}_3$

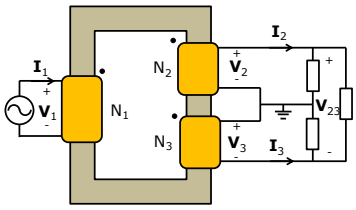


V2G, V3G are 180 deg. apart wrt ground

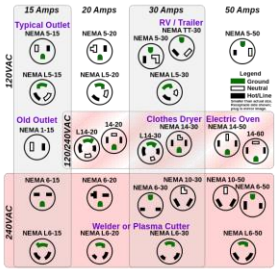
Center-Tapped Transformers

Center tapped transformers used to obtain 120/240V in residences





NEMA Outlet types



Note: two "hot" lines for 240VAC

Instrument Transformers

- Direct measurement of high voltage or high current is not practical
  - Relays, meters, etc require much lower voltage and current
- Solution: use specialty xfmrs to step down voltage or current
- Two general types:
  - Current transformers (CTs)
  - Voltage transformers (VTs, also called PTs)
- Polarity is critically important when CTs, PTs are used as inputs to relays

Instrument Transformers

- CTs, PTs have specified ratios
  - Example: a 100:1 PT will output 10V if the primary voltage is 1,000V
  - Example: a 120:5 CT will output 5A if the primary current is 120 A
- Insulation rating, accuracy classes (ANSI C57.13) and burden are also important specifications

Voltage Transformer

- Step-down transformer
  - Primary in the kV range, secondary usually ~120V
  - Large number of primary turns, small number of secondary turns
  - VA rating usually less than 500 VA
- Insulation of VTs often a challenge due to large primary voltage
  - one approach is to capacitively couple the high voltage side

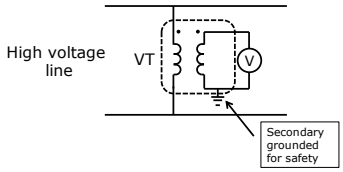
Voltage Transformer

Source: www.electro-meters.com/

Source: www.technovidyut.com

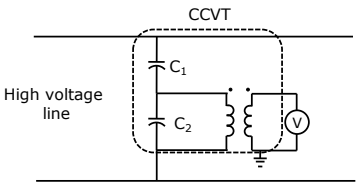
Soruce://tucsontransformer.com

Voltage Transformer



Voltage Transformer

- Capacitance-coupled voltage transformers are often used to measure voltages in the high 100kV range
- Utilizes voltage divider to measure lower voltage



Question

To reduce the insulation requirements of the transformer, should C_1 be larger or smaller than C_2?

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$C_1 < C_2$

By voltage divider, $|X_{C1}| > |X_{C2}|$, and $X_C = \frac{1}{\omega C}$ so we want $C_1 < C_2$

Example: C_1: 2,284 pF, C_2: 87,411 pF

Current Transformers

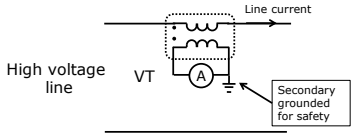
- Designed to measure current
  - Step down primary current (usually 5A secondary)
  - Large number of secondary turns, small number of secondary turns (often one turn)
  - Very small VA rating (<100)
- Secondary terminal must have low impedance connected (nearly shorted)

Current Transformers

Source: www.electro-meters.com/

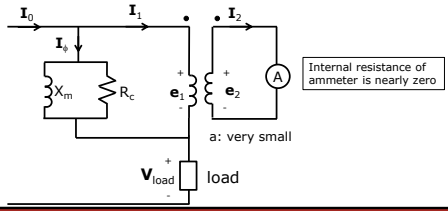
Source: www.ABB.com/

Current Transformers



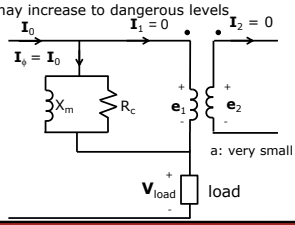
Current Transformers

- Under normal operation, secondary is nearly shorted
- $|\mathbf{e}_1| << |\mathbf{V}_{load}|$
- What happens if the secondary is opened?



Current Transformers

- $\mathbf{I}_0$ does not appreciably change
- Excitation current dramatically increases
  - R_c losses increase (CT may overheat)
  - $\mathbf{I}_m$ increases (may saturate CT and affect calibration)
- $|\mathbf{e}_2|$ may increase to dangerous levels



Current Transformers

- It is very important to never open-circuit a CT
- Short terminals before removing ammeter, relay, etc

Regulating Transformers

- Tap Changing Xmfr: transformer with adjustable turns ratio. Used to control (or maintain) the voltage magnitude on one side of the transformer.
- Phase-shifting Xfmr: transformer capable of controlling the voltage phase shift from primary to secondary. Used to control flow of real power in transmission systems

Summary

- Autotransformers are commonly used as they are cheaper and have greater power density than two-winding transformers
- CTs and VTs (PTs) are instrument transformers used to step down high current and voltage to practical levels for meters and relays
- CTs should never be open-circuited